

XVIII.—*Experiments to determine the difference in the Number of Vibrations made by an Invariable Pendulum in the Royal Observatories of Greenwich and Altona. By Captain EDWARD SABINE of the Royal Artillery, Secretary to the Royal Society.*

Read March 25th, 1830.

THE invariable pendulum No. 12, with which these experiments were made, was vibrated in the Royal Observatory at Greenwich in July 1828; in the Royal Observatory at Altona in September and October of the same year; and again at the Royal Observatory at Greenwich in August 1829. The mean of the results obtained at Greenwich, in July 1828 and in August 1829, give the rate of this pendulum at Greenwich, to be compared with its rate obtained at Altona.

The experiments in July 1828 have been already printed in the Phil. Trans. for 1829, Part I. pp. 100-102; the result was as follows:

Therm.	Barom.	Vibrations in Vacuo at 61°.5.
61.50 . . .	29.446 . . .	85970.00

In the experiments in August 1829 (Table A), the same barometer, thermometer, planes, and fixed support were used as in the preceding experiments. The rate of GRAHAM'S clock employed in observing coincidences was supplied by Mr. THOMAS GLANVILLE TAYLOR by daily comparison with the Greenwich transit clock. The following is an abstract of the results in Table A.

Greenwich, August 1829 ; Experiments with Pendulum 12.

	Therm.		Barom.		Vibrations.		Corrected to 63.53.
Aug. 8	. 63.87	. .	30.102	62.5	. .	85959.22	. . 85959.37
8	. 65.53	. .	30.072	64.5	. .	85958.41	. . 85959.29
9	. 62.50	. .	29.988	62.0	. .	85959.76	. . 85959.31
9	. 64.45	. .	29.951	65.0	. .	85959.24	. . 85959.64
9	. 64.95	. .	29.908	66.5	. .	85959.04	. . 85959.66
10	. 62.90	. .	29.806	62.0	. .	85959.63	. . 85959.35
10	. 63.55	. .	29.829	63.5	. .	85959.29	. . 85959.30
11	. 61.50	. .	30.020	60.0	. .	85960.27	. . 85959.38
11	. 62.50	. .	30.047	62.0	. .	85959.79	. . 85959.34
	<u>63.53</u>		<u>29.970</u>	<u>63.0</u>			<u>85959.404</u>
			— .090 red ⁿ . to 32°.	Red ⁿ . for 29.9 in.			
			+ .019 capillary.	of air at 63° .5			
			<u>29.900</u>	at 32°.		Mean	<u>85969.33</u>

The two results then at Greenwich are as follows :

		Vibrations.			Vibrations.
July	1828 . 61.50	. 85970.00	. Corrected to 62.5	=	85969.56
August	1829 . 63.53	. 85969.33	. Corrected to 62.5	=	85969.78
	<u>62.5</u>			Mean	<u>85969.67</u>

In Altona the pendulum is vibrated in an apartment on the ground floor of M. SCHUMACHER's house, appropriated to pendulum experiments. The door of this apartment is double, and the windows are double sashed, for the purpose of preserving an uniform temperature: a strong mahogany plank is fixed securely to the wall. The agate planes were screwed on it, and the telescope for observing coincidences was stationed in an aperture made for the purpose in the wall opposite to the pendulum, so that the coincidences were observed without entering the room. The clock for observing coincidences, with which M. SCHUMACHER was so kind as to supply me, was BREGUET, No. 3405, the admirable going of which during five centuries has recently been published. The

rate of this clock during the experiments was furnished by Lieut. NEHUS of the Royal Danish Engineers, assistant to M. SCHUMACHER in the Trigonometrical Survey of Denmark ; who for that purpose compared it daily with the transit clock of the Altona Observatory at those hours which were not suitable for giving its rate whilst the pendulum was in vibration. The heights of the barometer were furnished by M. PETERSON, assistant in the Observatory, from M. SCHUMACHER's standard barometer. The height of the pendulum above the level of the sea in M. SCHUMACHER's house was 15.1 toises.

Having an opportunity on this occasion of comparing the thermometer graduated in 1823 by Mr. DANIELL and myself, and employed in the present experiments, as well as in all the former determinations which I have made with invariable pendulums, with a standard thermometer presented by M. BESSEL to M. SCHUMACHER, I was anxious to avail myself of it ; and M. SCHUMACHER with great kindness undertook himself to make the comparison. The thermometers were compared by immersing the bulbs to the same level in water warmed very gradually in a chronometer stove by means of a small night lamp, and suffered again to cool ; the thermometers being compared both in the ascending and descending temperatures. I copy the following particulars of the comparison from M. SCHUMACHER's memorandum.

“ B. . . . are the readings of M. BESSEL's thermometer.

E. B. . . are the equations of M. BESSEL's thermometer.

R. T. . . are the real temperatures.

S. . . . are the readings of M. SABINE's thermometer.

E. S. . . are the equations of M. SABINE's thermometer.

1828. Oct. 20.

h	m		S.		B.		E. B.		R. T.		E. S.
1	38	P.M.	. 59.6	. 60.0	. -0.20	. 59.80	. +0.20				
1	43		. 60.0	. 60.5	. -0.20	. 60.30	. +0.30				
2	33		. 65.0	. 65.3	. -0.23	. 65.07	. +0.07				
3	24		. 70.2	. 70.6	. -0.26	. 70.34	. +0.14				
5	0		. 78.7	. 81.1	. -0.32	. 80.78					
7	0		. 86.35	. 86.7	. -0.38	. 86.32	. -0.02				
9	25		. 91.75	. 92.1	. -0.44	. 91.66	. -0.09				
11	47		. 94.60	. 95.3	. -0.47	. 94.83	. +0.23				

Oct. 21.

^h	^m		S.	B.	E. B.	R. T.	E. S.
7	18	A.M.	71.1	71.4	-0.27	71.13	+0.03
8	35		68.9	69.1	-0.25	68.85	-0.05
10	23		66.0	66.3	-0.24	66.06	+0.06
11	5		65.25	65.5	-0.23	65.27	+0.02
1	10	P.M.	63.1	63.4	-0.22	63.18	+0.08
3	47		61.1	61.3	-0.21	61.09	-0.01
4	03		61.0	61.2	-0.21	60.99	-0.01
4	22		60.75	61.0	-0.21	60.79	+0.04

Oct. 22.

6	38	A.M.	56.15	56.3	-0.18	56.12	-0.03
7	53		55.8	56.1	-0.18	55.92	+0.12
8	20		55.7	56.0	-0.18	55.82	+0.12
10	40		55.5	55.7	-0.18	55.52	+0.02
11	13		55.4	55.6	-0.18	55.42	+0.02
3	55	P.M.	56.25	56.55	-0.18	55.37	+0.12

The freezing point was found quite correct in pounded melting ice."

On examining the particulars of this comparison, it may be fairly inferred that between the limits compared, that is, between the temperatures of 55° and 90°, the indications of the two thermometers agree every where to less than a tenth of a degree; this agreement is the more satisfactory as it includes a part of the scale of my thermometer, in which the graduation by Mr. DANIELL and myself differed a whole degree from the original graduation of the maker. It is probable that M. BESSEL's thermometer indicates temperatures more often higher than mine, by a few hundredths of a degree, than lower by the same small quantities; hundredths of a degree are, however, quantities to be spoken of with much confidence, and may safely be neglected on the present occasion.

The experiments with the pendulum at Altona are given in Table B; and the following is an abstract of the results.

Altona ; September and October 1828. Experiments with Pendulum 12.

	Therm.	Barom.	Vibrations.	Corrected to 58.32.
Sept. 20 . .	60.93 . .	30.267 . .	85968.46 . .	85969.61
20 . .	60.95 . .	30.267 . .	85968.47 . .	85969.63
20 . .	60.52 . .	30.243 . .	85968.54 . .	85969.51
20 . .	60.42 . .	30.219 . .	85968.54 . .	85969.46
21 . .	59.63 . .	30.139 . .	85968.91 . .	85969.49
21 . .	60.10 . .	30.135 . .	85968.74 . .	85969.52
21 . .	60.33 . .	30.115 . .	85968.81 . .	85969.69
22 . .	60.55 . .	29.855 . .	85968.64 . .	85969.62
22 . .	60.60 . .	29.873 . .	85968.67 . .	85969.67
23 . .	60.71 . .	29.994 . .	85968.73 . .	85969.78
Oct. 1 . .	60.17 . .	29.566 . .	85969.16 . .	85969.97
1 . .	60.30 . .	29.578 . .	85969.17 . .	85970.04
2 . .	60.35 . .	29.688 . .	85969.18 . .	85970.07
2 . .	60.02 . .	29.688 . .	85969.29 . .	85970.04
3 . .	59.40 . .	29.976 . .	85969.45 . .	85969.93
4 . .	58.55 . .	29.913 . .	85969.62 . .	85969.72
8 . .	57.50 . .	29.381 . .	85970.19 . .	85969.83
8 . .	56.70 . .	29.433 . .	85970.49 . .	85969.78
15 . .	55.05 . .	30.030 . .	85971.25 . .	85969.81
15 . .	54.60 . .	30.030 . .	85971.35 . .	85969.71
21 . .	53.70 . .	30.195 . .	85971.89 . .	85969.86
22 . .	54.03 . .	30.041 . .	85971.74 . .	85969.86
23 . .	55.02 . .	30.041 . .	85971.29 . .	85969.84
23 . .	55.40 . .	29.835 . .	85971.10 . .	85969.82
24 . .	55.40 . .	29.982 . .	85971.20 . .	85969.92
24 . .	55.43 . .	29.982 . .	85971.20 . .	85969.93
	<u>58.32</u>	<u>29.941</u>	<u>85969.77</u>	<u>85969.77</u>
Red ⁿ . for 29.94 inches of air at 58.32 + 10.07				<u>85979.84</u>

The rate at Greenwich, with which this rate at Altona is to be compared, is 85969.67 vibrations at $62^{\circ}.5$. Reducing both these rates to a mean temperature of 60° , in the proportion of 0.44 vibration to one degree of FAHRENHEIT, they become respectively 85979.77 at Greenwich, and 85979.10 at Altona: whence we have an acceleration at Altona of 8.33 vibrations per diem.

TABLE A.—Vibrations of Pendulum 12 at Greenwich, August 1829; on the fixed iron support in the Pendulum room. The Barometer employed was the standard barometer of the Royal Observatory; the Thermometer was Captain SABINE's standard thermometer; the Arc was the same that had been used at Greenwich in July 1828; and at Altona in September and October 1828.

Exp. 1. August 8th. Clock making 86309.45 Vibrations. Barom. $\left\{ \begin{smallmatrix} 30.119 \\ 30.085 \end{smallmatrix} \right\}$ 30.102 in. 62°.5.									
No. of Coincid.	Therm.	Times of			Arc.	Mean Therm.	Mean Interval.	Correction for Arc.	Vibrations in 24 hours.
		Disapp.	Reapp.	Coincidence.					
1	61.3	m s 27 19	m s 27 23	h m s 7 27 21	0.85	} 63.87	s 492.46	s + 0.30	85959.22
33	66.0	.....	.....	12 0 0					
45	64.3	28 22	28 36	1 28 29	0.12				

Exp. 2. August 8th. Clock making 86309.73 Vibrations. Barom. $\left\{ \begin{smallmatrix} 30.085 \\ 30.060 \end{smallmatrix} \right\}$ 30.072 in. 64°.5.									
1	64.4	m s 37 11	m s 37 17	h m s 1 37 14	0.86	} 65.53	s 490.89	s + 0.31	85958.41
	67.1	.....	.....	3 0 0					
41	65.1	4 14	4 45	7 4 29.5	0.14				

Exp. 3. August 9th. Clock making 86309.73 Vibrations. Barom. $\left\{ \begin{smallmatrix} 30.004 \\ 29.973 \end{smallmatrix} \right\}$ 29.988 in. 62°.									
1	61.7	m s 4 51	m s 4 57	h m s 8 4 54	0.72	} 62.5	s 492.84	s + 0.30	85959.76
29	63.3	54 47	55 00	11 54 53.5	0.20				

Exp. 4. August 9th. Clock making 86309.70 Vibrations. Barom. $\left\{ \begin{smallmatrix} 29.973 \\ 29.930 \end{smallmatrix} \right\}$ 29.951 in. 65°.									
1	63.4	m s 3 25	m s 3 30	h m s 12 3 27.5	0.80	} 64.45	s 490.0	s + 0.39	85959.24
27	65.5	36 34	36 45	3 36 39.5	0.23				

TABLE A. (Continued.)

EXP. 5. August 9th. Clock making 86309.70 Vibrations. Barom. $\left\{ \begin{smallmatrix} 29.930 \\ 29.886 \end{smallmatrix} \right\}$ 29.908 in. 66°.5.									
No. of Coincid.	Therm.	Times of			Arc.	Mean Therm.	Mean Interval.	Correction for Arc.	Vibrations in 24 hours.
		Disapp.	Reapp.	Coincidence.					
1	65.4	m s 44 57	m s 45 2	h m s 3 44 59.5	0.82	} 64.95	s 491.67	s + 0.43	85959.04
31	64.5	50 41	50 58	7 50 49.5	0.22				

EXP. 6. August 10th. Clock making 86309.70 Vibrations. Barom. $\left\{ \begin{smallmatrix} 29.804 \\ 29.808 \end{smallmatrix} \right\}$ 29.806 in. 62°.									
1	62.8	m s 37 17	m s 37 24	h m s 7 37 20.5	0.91	} 62.9	s 492.59	s + 0.38	85959.63
39	63.0	49 12	49 26	12 49 19	0.18				

EXP. 7. August 10th. Clock making 86309.75 Vibrations. Barom. $\left\{ \begin{smallmatrix} 29.808 \\ 29.850 \end{smallmatrix} \right\}$ 29.829 in. 63°.5.									
1	63.2	m s 57 49	m s 57 53	h m s 12 57 51	0.84	} 63.55	s 492.15	s + 0.29	85959.29
44	63.9	50 19	50 48	6 50 33.5	0.12				

EXP. 8. August 11th. Clock making 86309.75 Vibrations. Barom. $\left\{ \begin{smallmatrix} 30.000 \\ 30.040 \end{smallmatrix} \right\}$ 30.020 in. 60°.									
1	61.0	m s 21 51	m s 21 55	h m s 8 21 53	0.97	} 61.5	s 493.29	s + 0.47	85960.27
36	62.0	9 31	9 45	1 9 38	0.19				

EXP. 9. August 11th. Clock making 86309.75 Vibrations. Barom. $\left\{ \begin{smallmatrix} 30.040 \\ 30.053 \end{smallmatrix} \right\}$ 30.047 in. 62°.									
1	62.4	m s 18 19	m s 18 25	h m s 1 18 22	0.84	} 62.5	s 492.88	s + 0.29	85959.79
42	62.6	54 52	55 28	6 55 10	0.12				

TABLE B.—Vibrations of Pendulum 12 at Altona; September 1828.

EXP. 1, 2, 3, 4. September 20th. Clock making 86436.48 Vibrations.																	
No. of Coincid.	Therm.	Times of			Arc.	Mean Therm.	Mean Interval.	Correc- tion for Arc.	Vibrations in 24 Hours.	Barom.							
		Disapp.	Reapp.	Coincidence.													
1	60.5	m s	m s	} h m s	°	}	s	s	}	°							
2		43 43	43 49								9 49 55.33	0.515	60.93	369.17	+0.24	85968.46	30.267 61
3	60.9	56 2	56 5														
	61.0	.....	.....	11													
24	61.1	5 13	5 21	12 5 17	0.250												
	61.1	.....	.....	1													
50	60.8	45 4	45 35	} 2 51 28.67	0.100	}	s	s	}	°							
51		51 13	51 45														
52	60.8	57 21	57 54														
Fresh impulse.																	
1	60.7	10 25	10 29	} 3 16 37.17	0.560	}	s	s	}	°							
2		16 33	16 39														
3	60.8	22 42	22 49														
27	60.3	50 12	50 43	5 50 27.5	0.210												
Fresh impulse.																	
1	60.8	46 55	47 5	} 7 53 9.17	0.575	}	s	s	}	°							
2		53 5	53 14														
3	60.8	59 14	59 22														
38	60.0	34 32	34 52	} 11 40 50.83	0.165	}	s	s	}	°							
39		40 40	41 1														
40	60.1	46 49	47 11														

EXP. 5, 6, 7. September 21st. Clock making 86436.75 Vibrations.															
1	59.3	m s	m s	h m s	°	}	s	s	}	°					
26	59.8	15 21	15 28	7 15 24.5	0.570						59.63	369.275	+0.29	85968.91	30.139 61
39	60.4	18 22	18 38	9 18 30.5	0.290						60.10	369.306	+0.08	85968.74	30.135 61
	60.4	9 11	9 24	11 9 17.5	0.160										
Fresh impulse.															
1	60.4	33 38	33 42	11 33 40	0.510	}	s	s	}	°					
	60.4			1 0 0							60.33	369.292	+0.17	85968.81	30.115 61
37	60.2	15 4	15 25	3 15 14.5	0.160										

EXP. 8 and 9. September 22nd. Clock making 86436.66 Vibrations.																	
1	59.5	m s	m s	h m s	°	}	s	s	}	°							
2		40 41	40 47	9 46 53	0.535						60.55	369.216	+0.18	85968.64	29.855 60		
3	60.0	52 59	53 5														
	60.9	.....	.....	11 14													
38	61.0	28 18	28 31	} 1 34 34	0.160	}	s	s	}	°							
39		34 26	34 43														
40	61.0	40 35	40 51														
Fresh impulse.																	
1	61.0	46 36	46 40	} 1 52 47.33	0.595	}	s	s	}	°							
2		52 45	52 50														
3		58 54	58 59														
	60.6	.....	.....	3 50													
45	.....	17 13	17 35	} 6 23 34.17	0.120	}	s	s	}	°							
46		23 27	23 41														
47	60.2	29 30	29 59														

TABLE B. (Continued.)

EXP. 10. September 23rd. Clock making 86436.85 Vibrations.										
No. of Coincid.	Therm.	Times of			Arc.	Mean Therm.	Mean Interval.	Correc- tion for Arc.	Vibrations in 24 Hours.	Barom.
		Disapp.	Reapp.	Coincidence.						
1	°	m s	m s	} h m s	0.645	} 60.71	s 369.142	s +0.19	85968.73	29.994 60
2	60.25	21 46	21 48							
3	.....	27 54	27 57							
	60.9	34 3	34 7	} 11	0.115	} 60.71	s 369.142	s +0.19	85968.73	29.994 60
	60.9	.....	.....							
										
48		10 44	11 9	} 2 17 5.5	0.115	} 60.71	s 369.142	s +0.19	85968.73	29.994 60
49	60.8	16 54	17 16							
50	.....	23 5	23 25							

EXP. 11 and 12. October 1st. Clock making 86437.45 Vibrations.										
1	°	m s	m s	} h m s	0.60	} 60.17	s 368.97	s +0.24	85969.16	29.566 61
31	59.95	51 7	51 11							
32	.....	55 28	55 49							
32	60.4	1 36	1 57	} 1 1 47	0.20	} 60.17	s 368.97	s +0.24	85969.16	29.566 61
33	.....	7 46	8 6							
	Fresh impulse.									
1	60.4	14 25	14 31	} 1 14 28	0.590	} 60.3	s 368.98	s +0.23	85969.17	29.578 61
32	.....	24 57	25 16							
33	60.2	31 3	31 27							
34		37 14	37 35	} 4 31 15.33	0.200	} 60.3	s 368.98	s +0.23	85969.17	29.578 61
										
										

EXP. 13 and 14. October 2nd. Clock making 86437.70 Vibrations.																	
1	°	m s	m s	} h m s	0.510	} 60.35	s 368.83	s +0.19	85969.18	29.688							
2	60.05	47 0	47 5														
3	.....	53 9	53 15														
	60.70			} 11	0.190	} 60.35	s 368.83	s +0.19	85969.18	29.688							
31	.....	45 7	45 31														
32	60.30	51 19	51 37														
33		57 30	57 44	} 12 51 28	0.190	} 60.35	s 368.83	s +0.19	85969.18	29.688							
	Fresh impulse.																
1	60.20	4 38	4 44														
33		21 15	21 36	} 1 4 41	0.550	} 60.025	s 368.91	s +0.21	85969.29	29.688							
34	59.85	27 23	27 47														
35	.....	33 32	33 57														
				} 4 27 35	0.190	} 60.025	s 368.91	s +0.21	85969.29	29.688							
																	
																	

EXP. 15. October 3rd. Clock making 86437.58 Vibrations.										
1	°	m s	m s	} h m s	0.610	} 59.40	s 369.089	s +0.25	85969.45	29.976
2	.....	4 29	4 32							
3	59.45	10 37	10 41							
	59.70			} 10 4 30.33	0.610	} 59.40	s 369.089	s +0.25	85969.45	29.976
31	59.30	2 46	3 2							
32	.....	8 55	9 11							
33	59.30	15 4	15 20	} 11 0	0.210	} 59.40	s 369.089	s +0.25	85969.45	29.976
										
										

TABLE B. (Continued.)

EXP. 16. October 4th. Clock making 86437.43 Vibrations.																					
No. of Coincid.	Therm.	Times of			Arc.	Mean Therm.	Mean Interval.	Correc- tion for Arc.	Vibrations in 24 Hours.	Barom.											
		Disapp.	Reapp.	Coincidence.																	
1	58.55	m s	m s	h m s	0.670	} 58.55	s 369.32	s +0.28	85969.62	29.913											
36	.....	38 55	38 59	10 38 57	0.200																
37	58.55	14 12	14 52	} 2 20 32.5																	
38	.....	20 22	20 43																		
		26 32	26 54																		

EXP. 17. October 8th. Clock making 86437.51 Vibrations.																					
1	57.6	m s	m s	h m s	0.580	} 57.5	s 369.75	s +0.20	85970.19	29.381											
39	.....	44 44	44 50	2 44 47	0.160																
40	57.4	38 48	39 7	} 6 45 7.17																	
41	.....	44 57	45 17																		
		51 7	51 27																		

EXP. 18. October 9th. Clock making 86437.51 Vibrations.																					
1	56.8	m s	m s	h m s	0.535	} 56.7	s 370.014	s +0.19	85970.49	29.433											
34	.....	54 14	54 19	9 54 16.5	0.180																
35	56.6	17 40	17 54	} 1 23 57																	
36	.....	23 50	24 5																		
		30 1	30 12																		

EXP. 19 and 20. October 15th. Clock making 86437.67 Vibrations.																					
1	55.2	m s	m s	h m s	0.60	} 55.05	s 370.44	s +0.26	85971.25	30.030											
2	.....	12 13	12 16	1 18 24.67	0.23																
3	54.9	18 23	18 27	3 58 56																	
28	.....	24 33	24 36																		
	Fresh impulse.																				
1	54.9	m s	m s	h m s	0.58	} 54.6	s 370.57	s +0.21	85971.35	30.030											
35	.....	23 45	23 49	4 23 47	0.19																
36	54.3	53 38	53 55	} 7 59 56.83																	
37	.....	59 47	0 7																		
		5 56	6 18																		

EXP. 21. October 21st. Clock making 86437.62 Vibrations.										
1	54.0	m s	m s	h m s	0.59	} 53.7	s 371.04	s +0.21	85971.89	30.195
36	53.4	31 3	31 8	12 31 5.5	0.18					
		7 20	7 44	4 7 32						

EXP. 22. October 22nd. Clock making 86437.56 Vibrations.																					
1	53.9	m s	m s	h m s	0.63	} 54.03	s 370.94	s +0.24	85971.74	30.041											
	54.0	29 15	29 17	11 29 16	0.18																
39	.....	12 30																			
40	54.2	24 0	24 22	} 3 30 22.67																	
41	.....	30 13	30 34																		
		36 22	36 45																		

TABLE B. (Continued.)

Exp. 23 and 24. October 23rd. Clock making 86437.34 Vibrations.												
No. of Coincid.	Therm.	Times of			Arc.	Mean Therm.	Mean Interval.	Correc- tion for Arc.	Vibrations in 24 Hours.	Barom.		
		Disapp.	Reapp.	Coincidence.								
1	54.4	m s 39 51	m s 39 56	h m s 9 39 53.5	0.60	} 55.025	s 370.76	s +0.23	85971.29	30.041		
	55.1	.....	.....	10 40								
	55.3	.....	.....	11 50								
35	55.3	9 50	10 9	1 9 59.5	0.19	} 55.4	370.50	+0.34	85971.10	29.835		
	Fresh impulse.											
1	55.3	16 28	16 32	1 16 30	0.61							
19	55.5	7 34	7 44	3 7 39	0.32							
Exp. 25 and 26. October 24th. Clock making 86437.45 Vibrations.												
1	55.4	m s 25 12	m s 25 16	h m s 10 25 14	0.60	} 55.4	s 370.59	s +0.24	85971.20	29.982		
33	55.4	42 45	43 1	1 42 53	0.20							
	Fresh impulse.											
1	55.4	49 50	49 52	1 49 51	0.61	} 55.43	370.57	+0.26	85971.20	29.982		
	55.5			4								
28	55.4	36 25	36 48	4 36 36.5	0.22							